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ELECTROMYOGRAPHIC ACTIVITY OF BACK MUSCLES DURING ERECT UNSUPPORTED SITTING WITH VARYING SEAT HEIGHTS

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ELECTROMYOGRAPHIC ACTIVITY OF BACK MUSCLES DURING ERECT UNSUPPORTED SITTING WITH VARYING SEAT HEIGHTS submitted by CONNE ROBERTSHAW in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

The purpose of the study was to determine if electromyographic activity of back muscles at the tenth thoracic, and the first, third, and fifth lumbar spinal levels, in erect unsupported sitting, differed between four positions of seat height. The reference seat height (Position One) for each subject was established by the subject position of thighs horizontal, lower legs vertical, knee angles 90°, and feet supported. Position Two was with a seat height of five cm higher than Position One. Positions Three and Four were with seat heights of five cm lower and ten cm lower than Position One, respectively. The fifteen normal female subjects ranged in age from 22 to 35 years, in weight from 49 to 68 kg, and in height from 155 to 175 cm. Subjects were also asked to rank the four positions of seat height with respect to comfort.

Electromyographic data was analyzed using an analysis of variance, one way classification for each spinal level. Sitting comfort data was analyzed with the Kolmogorov-Smirnov One-Sample Test for each position of seat height. In accordance with the limitations and delimitations imposed on the study, electromyographic data at each of the four spinal levels was consistent with the hypotheses that there

was no difference between the four positions of seat height. The fifteen subjects showed no significant difference in preferences among the four positions of seat height.

Electromyographic activity of back muscles has previously been demonstrated to be a reliable index of mechanical stress acting on the spine. Therefore, it was concluded that spinal stress and sitting comfort, in erect unsupported sitting, were similar for the four positions of seat height examined.

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CHAPTER I

INTRODUCTION

Background to the Problem

The objective of the study was to determine the effect of varying seat heights on electromyographic (EMG) activity of back muscles during erect unsupported sitting. The load on lumbar discs in unsupported sitting has been reported to be approximately three times segment weight above the measured level.[1] Intradiscal pressure (IDP) was 30 percent greater in unsupported sitting than in standing at the third lumbar disc.[1] Static muscle work is known to be required to maintain an upright body posture.[2] Mechanical stress on the lumbar spine, as expressed by IDP and EMG activity of back muscles, was reduced when the trunk was supported in sitting.[2] Andersson et al[2] considered the backrest of the chair to be the most important support parameter. However, the backrest is frequently not used by the occupant of the chair, when work is performed.[2,3,4,5] Such a nonuse of the backrest may, in part, be necessitated due to the effect of seat height given the task requirements and the

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anthropometric characteristics of the operatives. A large number of persons in modern industrial societies work in the seated posture. Unsupported sitting, therefore, is a commonly used work position, which subjects the lumbar spine to considerable mechanical stress. Yet, the effect of alterations in seat height of the chair on postural activity of back muscles in unsupported sitting has not been adequately studied.

Statement of the Problem

Controversy exists in the literature regarding the ideal sitting posture, and the effect of variations in seat height on spinal structures. Physical therapists, acting to advise patients in the prevention and treatment of low back pain, have not had sufficient information available to adequately describe the sitting position. Advice to patients regarding the sitting posture and chair selection, in back care education programs in Canada, frequently have not reflected known scientific facts. The most important task of the physical therapist, in rehabilitation of patients with low back pain, is to give ergonomic and postural advice based on present knowledge of spinal loading.[6] Physical therapists cannot do this if the necessary information is not available.

Objectives of the Study

The objectives of the study were:

1. To determine the effects of varying seat heights on EMG activity of back muscles during unsupported sitting.
2. To perform a subjective comfort assessment as a function of seat height alteration.

Research Hypotheses

1. Alternate: The mean EMG activity of back muscles, expressed as a percentage of a standard stress at each of the four vertebral levels, will differ between the four positions of seat height.

   Null: The mean EMG activity of back muscles, expressed as a percentage of a standard stress at each of the four vertebral levels, will not differ between the four positions of seat height.
2. Alternate: Sitting comfort will differ between the four positions of seat height.

   Null: There will be no difference in sitting comfort between the four positions of seat height.

Significance of the Study

Andersson et al[2], Burandt and Grandjean[5] and Kroemer[7] agreed that a chair with adjustable seat height is necessary

to accommodate persons of different body dimensions in sitting; however the optimum seat height of the chair was not agreed upon. The upright sitting position has been reported to produce flattening of the lumbar lordosis as compared to standing.[8,9] Controversy exists in the literature regarding the ideal sitting posture of an individual in relation to seat height. Back care education programs, conducted by physical therapists in Canada have frequently not been based on the present body of knowledge of the sitting posture and chair selection. In the author's opinion,education of patients in good sitting habits and chair selection have often been considered by clinicians to be unimportant or unnecessary in back care education programs. Further clarification of the factors involved in chair selection and the sitting posture may aid in rectifying this situation.

Sitting is an integral part of life in modern industrial societies. Many hours of the day are spent in the seated posture. Mandal[4] stated that in the course of the twentieth century man will have evolved from an upright form to a sitting one; from <u>Homosapiens</u> to <u>Homosedens</u>. A portion of pathological conditions of the spine treated by physical therapists are thought to be related to prolonged sitting. Many lesions of other etiologies, seen by physical therapists, may be aggravated by sitting. Advice to patients regarding sitting and chair

selection must have a scientific basis if primary and secondary lesions related to sitting are to be effectively treated.

Wolf et al[10] reported that 80 percent of all Americans suffer from back pain at one time or another. Weiss[11] stated that it is likely that 75 percent of the American population suffer from back pain, and that it is the most expensive affliction on the welfare and Workman's Compensation rolls. Back pain is considered to be a significant problem in modern industrial societies. The exact etiology of pain production is uncertain. Pain occurs at the level of the greatest mechanical stress.[12] Exacerbation of low back pain has been reported to occur when patients subject their lumbar spines to increased mechanical load.[6,13] A relationship between sitting much of the day and low back pain may exist, as Nachemson and Morris[12] determined IDP to be about 30 percent greater in sitting than in standing at the third lumbar (L_3) disc. The approximate load on the L_3 disc in a 70 (kg) individual has been determined to be 70 kg in standing as compared to 100 kg in unsupported sitting.[6] Information regarding seats and seating is, therefore, applicable to and of possible benefit to all sedentary individuals in modern industrial societies. Chair selection is of particular importance for persons engaged in occupations necessitating prolonged

sitting including business, industry and education.

Delimitations

The investigation was delimited as follows:

1. The study was limited to EMG activity of back muscles recorded with surface electrode pairs placed three centimeters (cm) lateral and parallel to the tips of the spinous processes, on the right side of the body, at the levels of the tenth thoracic vertebra; and the first, third and fifth lumbar vertebrae (T_{10}, L_1, L_3, L_5), with an interelectrode distance of 4 cm.
2. The investigation was limited to erect unsupported sitting with the equivalent of 15 cm alteration in seat height from the subject position of thighs horizontal, lower legs vertical, knee angles 90° and the soles of the feet in contact with and resting on two 5 cm thick wooden blocks.
3. The investigation was limited to fifteen female subjects in the age range of 22 to 35 years, a range of height of 155 to 175 cm, and a range of weight of 49 to 68 kg. The study was limited to normal subjects without clinical histories of chronic low back pain or traumatic back pathology.

Limitations

The limitations imposed on the study were as follows:

1. Subject selection was made on a volunteer basis, and did not constitute a random sample of the population.
2. Measurement of intradiscal pressure and EMG activity of back muscles simultaneously would have provided added information, but was not feasible due to IDP measurements being invasive and of risk to the subjects.
3. The investigation did not account for individual differences in sitting habits, which may have effected EMG activity of back muscles in the standardized sitting positions.
4. Baseline EMG activity recorded in the flexion-relaxation position was dependent on the subject's ability to relax in the position, and was influenced by differences in the degree of relaxation obtained by each subject.

CHAPTER II

REVIEW OF THE LITERATURE

Disc Pathology and Prolonged Sitting

Low back pain is one of the most frequent and disabling conditions affecting people in their productive years.[13] Impairment of the back and spine are the most frequent cause of limitation of activity in persons less than 45 years old in the United States.[14] Low back pain has been reported to occur with equal frequency in men and women.[13,15]

Disc degeneration is thought to be capable of producing back pain and sciatica, although the exact mechanism of pain production and the precise relationship between the morbid anatomy and the symptomatology is uncertain.[16,17] Nachemson[1] stated that disc pathology should be considered in terms of a combination of anatomic, histologic, chemical and mechanical factors. Daily wear and tear may be a causative factor in disc degeneration.[1,18] Deformation of the disc in static loading, like all viscoclastic materials, depends on the magnitude of the load and the duration of loading.[19] Hirsch[19] demonstrated that with preloads in

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excess of 70 kg, the shock absorbing capacity of middle lumbar discs were considerably reduced, when they were subjected to rapidly applied forces. Lumbar discs are able to withstand short-lived stresses, but not prolonged stress maintained in one direction.[20]

A large part of production, education, transport, administration and relaxation take place in the sitting position.[4] Static work postures were reported to be one of the vocational factors associated with an increase in absence from work because of low back symptoms.[13] Magora[21] examined 429 patients with low back pain from eight occupations. The occurrence of back pain was attributed to prolonged continuation of a specific work posture required by the type of work.[21] Prolonged sitting, with infrequent changes of work posture, has been associated with the occurance of low back pain, and herniated lumbar intervertebral discs.[13,22]

EMG Activity of Back Muscles and Spinal Loading

A series of investigations of the sitting posture in relation to the components of a chair were conducted by Andersson et al[2,23,24,25,26] with simultaneous measurement of IDP, at the third lumbar disc, and EMG activity of back muscles. Throughout these studies seat height was held constant. The effect of variations in seat height on EMG

activity of back muscles in sitting has not previously been examined.

Andersson et al[2,23,24,25,26] made the assumption that minimal IDP and EMG activity of back muscles were desirable in sitting, so that mechanical stress on the spine would be reduced to the lowest possible amount. This assumption was indirectly supported by Kumar and Scaife[27] who suggested that prolonged muscular contraction and fatigue may produce low oxygen tension, accumulation of metabolites, and may also reduce blood circulation to a degree depending on the strength of contraction. Minimal static muscle contraction of back muscles is, therefore, desirable in sitting.

Intradiscal pressure measurement yields direct information of the load acting on the spine,[28] but require invasive procedures. Andersson et al[29] demonstrated linear relationships between myoelectric activity of back muscles and intradiscal pressure, and the moments acting on the spine. Ortengren et al[28] in agreement with Andersson et al[29] suggested that EMG activity of back muscles may be used to study the load on the spine in static and dynamic situations. This evidence suggests that EMG activity of back muscles may be used as an index of spinal stress.

Waters and Morris,[30] in a study of electrical activity of the trunk muscles during walking, obtained all EMG recordings from the right side of the body, with the

assumption that electrical activity would be the same on both sides. Jonsson[31] demonstrated that there were no significant differences between the EMG activity of the erector spinae muscles on the right and left side of the body in symmetrical postures. Andersson et al[32] also later reported that EMG activity of back muscles was the same on both sides of the body in sitting with arms relaxed. There were no significant differences in EMG activity of back muscles between men and women in any age group in quiet sitting.[10] Andersson et al[33] also reported that there were no statistically significant differences in EMG activity of paraspinal muscles, between males and females in unsupported sitting.

Muscle Force and the Electromyogram

Muscle contraction is the last of a series of physiological processes, beginning with central nervous system excitation, and ending with the conduction of action potentials along the muscle fibers, which initiate muscle contraction.[34] Human motion and upright postures are the result of muscle contractions that are directly observable to only a limited extent.[34] A recording electrode located in the electromagnetic field of depolarized muscle will detect a potential or voltage, with respect to the ground, whose time excursion is known as an action potential.[35] The

EMG signal or myoelectric signal is the total signal seen at an electrode or differentially between two electrodes.[36] The myoelectric signal is the algebraic summation of all motor unit action potential trains from all active motor units within the pickup area of the recording electrodes.[35,36] The myoelectric signal must be amplified before it can be recorded, when it is then called an electromyogram.[36]

Parallelism between the amplitude of the electromyogram and muscle tension exists during isometric contraction (muscle contraction at a fixed length), regardless of the type of electrodes used, provided the conditions of the experiment are specified.[37] It is not possible to reproduce precisely the results of an experiment if the electrodes have been removed from the subject, or other conditions of the experiment have been altered.[37,38] Amplitude of the recorded signal (pen deflection) is a linear function of the input signal with the use of amplifiers with a flat rate frequency response in the frequency range of interest.[39] The amplitude of the electromyogram depends on: 1) the diameter of the depolarized muscle fibers, 2) the distance of the active muscle fibers from the recording electrodes, 3) the filtering properties of the electrodes, and 4) impedance (total skin resistance and resistance of intervening

tissue).[35] Electromyographic recording must, therefore, be carried out in one session with standardized electrode type, placement and body positions.

Use of EMG Surface Electrodes to Monitor Activity of Back Muscles

Use of surface electrodes is the method of choice where a global pickup of muscle activity is desirable.[35] Bouisset and Maton[40] demonstrated that a linear relationship exists between the integrated surface EMG and the integrated intramuscular EMG during static or isometric muscle activity. It was concluded that the surface activity was representative of the intramuscular activity.[40]

Andersson et al[23] conducted simultaneous measurements of EMG activity of paraspinal muscles and IDP at the level of the third lumbar disc in sitting. Bipolar recessed surface electrodes were used to obtain a representative signal from a large group of muscles suitable for the detection of major functional differences. Andersson et al[23,32] reported that surface electrode pairs, placed 3 cm lateral and parallel to the tip of the centers of the spinous processes at the levels of T_{10}, L_1, L_3, L_5 monitored activity of the longissimus and multifidus muscles. Wolf et al[10] using similar electrode placement, reported that the electromyogram represented activity from at least the longissimus and multifidus muscles.

Andersson et al[32] also noted that in the lower thoracic region the erector spinae group of muscles is covered by the trapezius and latissimus dorsi muscles, while in the lumbar region the erector spinae is covered only by the thoraco-lumbar fascia. The activity of trapezius and latissimus dorsi would, therefore, also be recorded on the electromyogram in the thoracic region in sitting.[32] The large interindividual differences that occurred in the electromyograms of the trapezius muscle were explained by the fact that trapezius does not function mainly as a postural muscle.[41] Similarly, the primary function of latissimus dorsi is to extend and medially rotate the arm.[42]

The contribution of the iliopsoas muscle to postural stabilization in sitting is presently unresolved. Andersson et al[23] monitored activity of the iliopsoas muscle, by needle electrode, in sitting and standing. They concluded that the psoas major is an active postural muscle in both sitting and standing, but only minor differences in myoelectric activity were observed between the two postures. Nachemson[43] reported an increase in iliopsoas activity in sitting as compared to standing. In contrast, Basmajian[44] reported no activity in the iliopsoas muscle in sitting.

Quantification of the Electromyogram

The electrical result of a motor unit twitch is an electrical discharge with a mean duration of 5 milliseconds (msec), and a total amplitude measured in microvolts (μV) when surface electrodes are employed.[35] The range of amplitude of the electromyogram obtained from surface electrodes with amplification is 0.01 to 5 millivolts (mV).[36] However, without knowledge of varying impedance, the voltage information is not too meaningful.[36] Impedance operant with surface recording electrodes is dependent upon 1) the skin site, 2) the subject, 3) the time, and 4) the skin preparation.[36] The basic noise level of the equipment is a function of source resistance, thermal noise, and amplifier noise, all of which contribute to the amplitude of the direct (raw) or integrated electromyogram.[45] Possible artifacts include the 60 Hz disturbance, the electrocardiogram (EKG) artifact and the motion artifact which are excluded from the electromyogram analysis.[45] Also, Jayasinghe et al[46] reported that the electromyogram obtained from the erector spinae group of muscles under sustained isometric contraction (fatigue) was of increased amplitude which increased progressively with time.

Analysis of the direct EMG recording may be conducted by measurement of peak to peak amplitude or maximum negative deflection.[47] Metric scales (mm) used to measure the

amplitude of the electromyogram permit evaluation of differences between magnitudes expressed in quantities.[34] The highest content of information is obtained when the magnitudes of the recordings are combined with absolute or relative units.[34,36,48,49] Activity levels within an EMG channel can only be related to the standard for that channel.[35]

Function of the Erector Spinae Muscles

Basmajian[35] stated that every muscle has several component parts which are recruited in different functions at different times. The stability of the spine is dependent largely on the action of the extrinsic support provided by the trunk musculature.[50] Electromyographic studies of the erector spinae muscle group have demonstrated low level postural activity during unsupported sitting.[8,23,31,35] Jonsson[31], in a study of individual muscles in the lumbar part of the erector spinae using EMG wire electrodes, reported activity of multifidus, slight activity of longissimus at the L_{3-5} levels, and slight activity of iliocostalis in some subjects in unsupported sitting. Donisch and Basmajian,[8] in a similar study, confirmed that the multifidi act primarily as stabilizers rather than prime movers of the vertebral column. The erector spinae muscle group, in both investigations,[8,31] was shown to display

different patterns of activity in the thoracic region as compared to the lumbar region. The forces exerted by the erector spinae muscle group in unsupported sitting functioned to balance the trunk against gravitational forces.[50,51] When EMG activity of back muscles in unsupported sitting was compared to sitting with backrest support, activity and thus spinal stress were higher to prevent the trunk from falling forward.[33]

Activity of the erector spinae muscle group has been shown to occur during the performance of flexion or attempted flexion of the trunk in sitting.[10,31] Morris et al[52] suggested that erector spinae activity in sagittal plane movements of the trunk occurred to oppose the forces of gravity. Floyd and Silver[53] first demonstrated that the erector spinae muscles became electromyographically inactive at a critical point during flexion in sitting (flexion-relaxation). Normal skeletal muscle has been shown to be electrically silent at rest.[35,54] Floyd and Silver[53] concluded that with increasing flexion there is an increase of tension in the intervertebral ligaments, until the flexed trunk is supported by those ligaments, at which point the erector spinae muscles relax. Radiography of the vertebral column in the flexion-relaxation position demonstrated that the degree of flexion of the spine in the standing position was greater than the degree of flexion in the sitting

position at the point that flexion-relaxation occurred.[53] Donisch and Basmajian[8] also reported that spontaneous electrical silence of the lumbar muscles occurred in extreme flexion in the sitting and standing positions in most subjects (n = 25), but only half of the subjects showed spontaneous inactivity of their thoracic muscles in both the seated and standing postures.

Extension of the trunk in the prone and the sitting postures produced a marked increase in activity in the whole of the lumbar part of the erector spinae muscles.[31,52,55] Donisch and Basmajian[8] reported that in extension from the flexed to the upright posture in sitting and standing, the erector spinae muscles do not always become immediately active when extension is begun, but rather short bursts of activity occurred when the extension movement was half completed. They concluded that in most persons the erector spinae muscles do not initiate extension from the fully flexed position. Support for this conclusion was given by the report of Floyd and Silver[53] who demonstrated that the initial extension movement in weight lifting usually takes place at the hip joints, and the erector spinae muscles remain relaxed or almost so, thereby placing the load on spinal ligaments.

In previous investigations[8,31,52,53,55] of extension of the trunk from the prone, sitting or standing positions, the

speed of movement was given as the normal or natural speed for each subject. In reference to the learning of motor behavior, Basmajian[35] stated that the best movements are performed with an economy of muscular action. With repetition and maturation, the brain has learned patterning of actions or movements by means of progressive inhibition of the inefficient mass responses that were natural to the child.[35] The natural rate of movement for each subject is governed by the Law of Minimal Shunt Action which states that muscle fibers are used only as necessary and sufficient to ensure that the transarticular force directed toward a joint is equal to the weight of the stabilized or moving part together with such additional centripetal force as may be required because of the velocity of the part when it is in motion.[35] This evidence suggests that alteration of the rate of movement from what is normal or natural for each subject would introduce physiologically uneconomical motor unit recruitment.

The Sitting Posture

Andersson et al[9] demonstrated through radiographic measurements that when moving from the standing to the unsupported sitting position, the lumbar lordosis decreases by an average of 38°. This reduction occurs mainly by posterior rotation of the pelvis, an average of 28°, and the

remaining 10° are accounted for by changes in the vertebral body angles of mainly the lower two lumbar segments.[9] Donisch and Basmajian[8] also reported that radiography has shown that posterior rotation of the pelvis is about 40° when a standing person sits down, and that this pelvic rotation is accompanied by a flattening of the lumbar lordosis. The posterior rotation of the pelvis that occurs in sitting as compared to standing, was reported to be the result of hamstring and gluteal muscle pull, created by the tension of their limited length.[3,18]

Andersson et al[33] defined the unsupported middle sitting position according to the force transmitted by the feet to the floor. In the unsupported middle sitting position the feet transmit about 25% of the body weight, and the center of gravity is above the ischial tuberosities.[33] Two different types of unsupported middle sitting were described (see Figure 1).[23] Straight unsupported sitting was described as being obtained by rotating the pelvis forward. The lumbar spine was usually straight or in slight lordosis. In relaxed unsupported sitting the lumbar spine was straight or in slight kyphosis. In both the relaxed and straight unsupported sitting positions the knees were flexed to 90°, feet were supported and arms hanging. When the straight position was compared with the relaxed position, a decrease in IDP was found but the myoelectric activity of

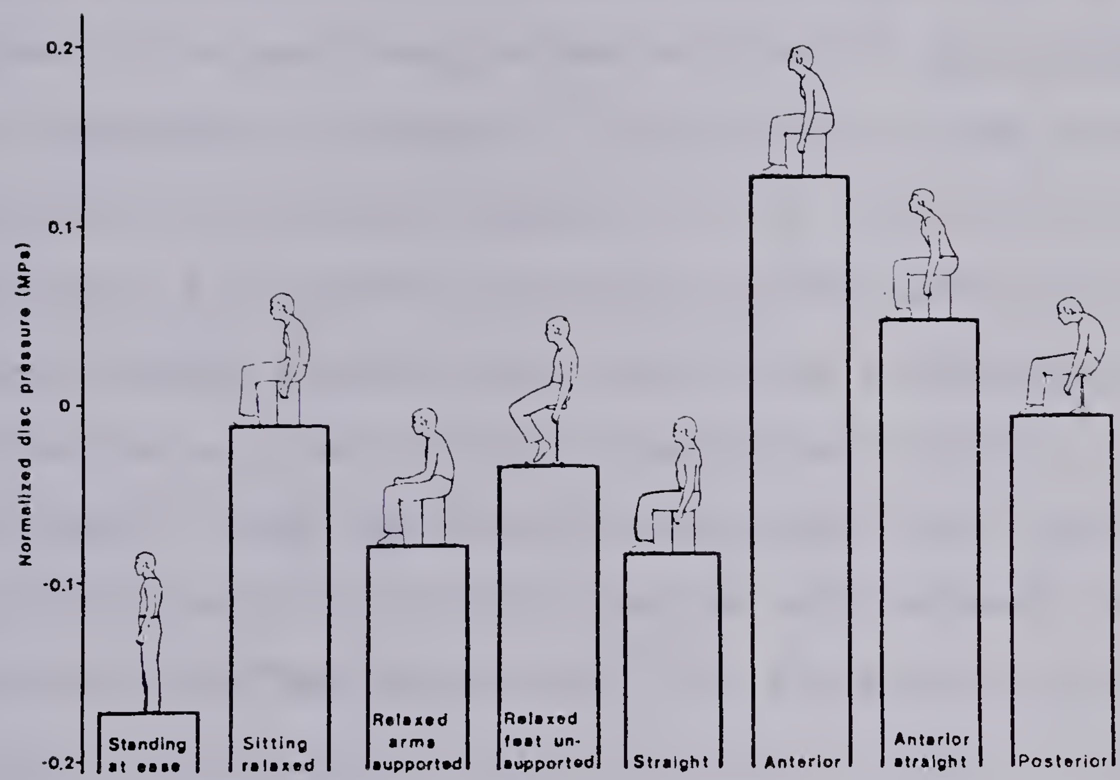

Figure 1. Mean values of normalized disc pressure in standing and unsupported sitting. From Andersson GBJ, Ortengren R, Nachemson A, Elfstrom G: Lumbar disc pressure and myoelectric back muscle activity during sitting. I. Studies on an experimental chair. Scand J Rehab Med 6: 108, 1974

back muscles remained unchanged.[23] Straight unsupported sitting has been reported to create a shorter lever arm for the force exerted by the weight of the upper body as compared to relaxed unsupported sitting.[56] When sitting, either relaxed or straight, a lower level of EMG activity was found in the lumbar region (L_1, L_3) than in the thoracic region (T_5, T_8, T_{10}).[23] Variation in EMG activity of back muscles between subjects was found to be considerable, in both the relaxed and straight unsupported sitting positions.[41] Both IDP at the third lumbar disc, and myoelectric activity of back muscles were reduced when the subject's trunk was supported.[23,41] Decreased EMG activity of back muscles and IDP were attributed to part of the body weight being transmitted to the backrest.[23] Andersson et al[23] recommended that a lumbar support should be incorporated into the backrest of the chair, and that the backrest itself should be inclined backward to at least 100°.

The backrest of the chair, which is considered to be of major importance in reducing mechanical stress on the lumbar spine in sitting, is frequently not used by the occupant of the chair.[5] Anterior sitting positions are usually adopted when desk work is performed.[2,3] Anterior sitting may be reached from middle sitting either by forward rotation of the pelvis keeping the spine straight or by little or no

rotation of the pelvis and marked kyphosis of the lumbar spine.[33] The highest EMG activity of paraspinal muscles and IDP at L_3 were recorded in the anterior sitting positions.[23] Intradiscal pressure was less in straight anterior sitting as compared to anterior sitting with marked lumbar kyphosis.[23] As the center of gravity falls in front of the ischial tuberosities in anterior sitting, the relatively higher load on the spine was interpreted as being the result of contraction of the paraspinal muscles to counteract the effect of gravity acting on the trunk.[23]

In posterior unsupported sitting, IDP was about the same as relaxed unsupported sitting, and myoelectric activity was at a lower level.[23] The posterior position was reached by rotating the pelvis backward, and flexing the lumbar spine to balance the trunk.[33] Relative relaxation of the back muscles in posterior unsupported sitting was interpreted as being due to the flexion of the lumbar spine with support of the trunk by spinal ligaments.[33] The increase in load arising from the restraint of the ligaments was compensated for by the decrease in load induced by the muscles.[23]

Higher disc pressure at L_3 was recorded in relaxed unsupported sitting with slight lumbar kyphosis than in straight unsupported sitting.[23] Andersson et al[2] stated that flattening or kyphosis of the lumbar spine in sitting

increases the load on the intervertebral discs. Farfan et al[57] reported a higher incidence of Schmorl's nodes in flat as opposed to lordotic lumbar spines. Akerblom[58] and Knutson et al[59] conducted EMG studies of paraspinal muscles in sitting, and recommended sitting with maintenance of the lumbar lordosis. Support of the lumbar spine was shown to promote relaxation of the back muscles.[58,59] Keegan[18], in a radiographic study of the lumbar spine in the sitting, standing and lying positions, concluded that the physiologically normal position of the adult spine was achieved with a thigh-trunk angle of 135°, as the lumbar lordosis was maintained and balanced muscle relaxation was obtained in the surrounding muscles. Present evidence, therefore, indicates that when sitting is used as a work position, the lumbar lordosis should be maintained.

Nachemson[60] reported that the line of gravity falls in most subjects, through the center of the third lumbar disc in standing, and about 4 cm in front of the disc in erect (straight) unsupported sitting. The increase in IDP at L_3 in sitting as compared to standing is therefore attributable to the eccentricity of the center of gravity producing additional axial compressive force on the spine. Nachemson[60] suggested that the force of the sacrospinalis muscles in sitting was small in comparison to that of the psoas muscle, and that psoas activity was in part

responsible for the increased load on the spine in sitting. In contrast, Andersson et al[9,23] proposed that muscle activity in sitting and standing were the same. They suggested that the increase in IDP in sitting, was in part, the result of deformation of the disc when the lumbar curve was flattened. The decrease in IDP produced as the lumbar spine was moved into lordosis, was explained by the discs then being closer to their normal wedge shape, with the greatest width being anterior.[23] A small increase in IDP at L_3 (0.7 kp/cm^2) occurred with 5° tilted loading of the disc which was independent of the externally applied load.[61] This finding was interpreted as being the result of increased tangential stress in the dorsal part of the annulus fibrosis of the disc.[61] This evidence suggests that the increase in intradiscal pressure in sitting as compared to standing is in major part attributable to the addition of gravitational forces, and in minor part the result of muscle forces, and deformation of or stress on the annulus fibrosis. The exact relationship between these factors and their precise contribution to the magnitude of intradiscal pressure and hence spinal loading, is presently disputed.

In contrast to the reports of Keegan,[18] Andersson[2,23] Akerblom,[58]and Knutsson et al[59]; Fahrni[62], and Hall[63] have suggested chair sitting with the back slumped (lumbar kyphosis), hips forward in the chair, and feet elevated with

knees bent. During the course of 12 years clinical practise in Saskatchewan and Alberta, the author has observed that physical therapists commonly advise patients to sit with their knees higher than their hips, thus producing a thigh-trunk angle of less than 90°, and flattening of the lumbar lordosis. These recommendations have not been subjected to the scrutiny of scientific investigation.

The Chair

The sitting posture an individual assumes depends on the design of the chair, his or her sitting habits and the task to be performed.[2] Akerblom[58] emphasized that the sitting posture is dynamic, and that no body position can be maintained indefinitely. Changes of position occur with forward and backward movement in the chair and with shifting weight from side to side. Darcus and Weddell[64] stated that changes of position in sitting promote circulation through fatigued muscles. The chair must, therefore, allow for changes of position, and not force the occupant into a fixed posture.

Previous investigators have identified relevant factors that must be considered in the selection of an appropriate seat height of the chair. A chair with an adjustable seat height was considered to be necessary to accommodate persons of different body dimensions (posterior thigh to heel

distance) in sitting.[2,5,7] However, lumbar vertebral posture was found to be largely secondary to the postural relationship between the trunk and the lower limbs, provided the inclination of the trunk remains constant.[65] The posture of the lumbar spine in sitting may therefore be altered either by changes of seat height or by changes in the height of the support for the feet.

The ischial tuberosities were considered to be the normal anatomical supports of the seated subject.[64] The skin over the ischial tuberosities may be modified to withstand prolonged pressure.[66] Fahrni[62] and Hall[63] recommended chair sitting with the knees higher than the hips, achieved either with the feet elevated on a stool, or with a low seat, the feet may rest on the floor. Akerblom[58] and Darcus and Weddell[64] suggested a seat height of slightly less or equal to the length of the lower leg, so that body weight would be supported by the ischial tuberosities, and compression of soft tissues of the posterior thighs could be avoided. Andersson et al[23] reported that in unsupported middle sitting, when the knee angles are 90°, weight bearing is on the ischial tuberosities. Bush[67] reported that pressures generated under the ischial tuberosities when subjects were seated with the feet supported, were in excess of 30 pounds per square inch. When subjects sat with legs hanging, ischial tuberosity pressures remained the same but

significantly higher thigh pressures resulted. Keegan[18] recommended a seat height of 40.64 cm to permit the feet to reach the floor.

The seat height required by an individual will be altered by changes of shoes to different heel heights. Floyd and Roberts[66] reported that in a chair designed for public use, a seat height of 43 cm accommodated 77 percent of men with a 2.5 cm heel, and 76 percent of women with a 4.5 cm heel. Low seats produced a sitting position with a thigh trunk angle of less than 90°.[66] The result was obliteration of the lumbar lordosis from tension on the hamstring muscles which rotated the pelvis posteriorly.[66] Very high seats, where the occupant's feet were unsupported, hastened the onset of back muscle activity.[66]

Mandal[4] designed a chair with a forward tilting seat, adjustable to a maximum of 15°. It was proposed that, as work in sitting is most frequently carried out by leaning forward in a bent posture, forward tilt of the chair seat would serve to preserve the lumbar lordosis.[4] However, Kroemer[7] stated that although a forward tilted seat maintains the lumbar lordosis, the continuous muscle action required to maintain the position may become fatiguing.

Floyd and Roberts[66] recommended a seat depth of 15 to 20 cm less than the sacral calf distance so that there is adequate clearance between the calf and the front of the

seat. Burandt and Grandjean[5] recommended a seat depth of 32 to 40 cm. If the seat was too long, the occupant would be forced to sit in lumbar kyphosis, and would not be able to alter his sitting position freely.[5] Seat width should allow for clearance of the trochanters, and permit lateral movement in the chair.[64,66] Floyd and Roberts[66] suggested that a seat width of 40 cm would accommodate all but the broadest individuals. They recommended a seat width of 47.5 cm for chairs that have arms.

The shape of the seat surface recommended was either uncontoured[7,66] or slightly concave.[18,58] Either design satisfies the principle considerations of allowing the occupant freedom of movement in the chair and weight bearing through the ischial tuberosities. However, controversy exists regarding ideal seat inclination. Floyd and Roberts[66] recommended a horizontal seat so that there is a less acute thigh-trunk angle, and change of position are facilitated. Akerblom[58], and Darcus and Weddell[64] recommended a seat that is tilted backward 3° to 5° so that there is no tendency to slide forward in the chair.

Kroemer[7] recommended a seat that is firm enough to provide support, achieved by padding with upholstery that does not compress more than 2.5 cm. Very hard seats produce discomfort in a short time.[64] Very soft seats were not recommended as body weight is then distributed to soft

tissues adjacent to the ischial tuberosities producing undue pressure and discomfort.[64]

A seat short in depth, with no horizontal struts between the front legs of the chair was recommended so that the occupant may bring his or her feet under the body in order to reduce muscular effort in rising.[66] Arm rests may be used to aid in getting up from the chair.[7] Stenographer's chairs were designed without arms to allow for freedom of movement of the arms and upper trunk.[7]

Sitting to Work

The chair is not an isolated entity, but rather must be considered in the context of its use. Floyd and Roberts[66] emphasized that in the design of a work area, the work surface and the chair must be considered as a single anthropometric unit. The height of the work surface should be such that the worker's elbows are at about the level of the table top in erect sitting; with shoulders relaxed and arms hanging loosely beneath the shoulders.[27] Table height should, therefore, be correlated to trunk height.[27] Andersson and Ortengren[24] reported that although the work activity produced the greatest influence on IDP at L_3 and EMG activity of back muscles, the vertical distance between the seat surface and the table top should be adjusted to fit the body dimensions of the occupant. At present, office

desks are not commonly adjustable in height. Horizontal clearance underneath the table top should be such that the worker is able to move his knees freely, and cross and extend his legs as he changes positions while working.[66]

Less et al[68] reported that work surfaces of 12° inclination increased work efficiency when compared to flat horizontal surfaces. Eastman and Kamon[69] reported that subjects had a more erect posture and less back movement (reduced EMG) when reading and writing at slanted desk surfaces as compared to horizontal surfaces. Slanted desk surfaces also reduced fatigue and discomfort of the back during prolonged desk work.[69]

Sitting Comfort and Behavior

Waschler and Learner[70], and Branton[71] agreed that the major difficulty in the evaluation and measurement of seat comfort is the lack of an accurate definition of comfort. Comfort has been defined as a feeling or affective state.[71] Branton[71] stated that sitting comfort varies subjectively on a continuum extending only from a state of indifference to extreme discomfort, as absence of discomfort does not necessarily entail a positive affect.

Sitting, like all postural activity, has been suggested to be normally undertaken for some purpose, which is unrelated to the height or other properties of the seat.[71]

Shackel et al[72] suggested that the level of comfort in sitting should be considered with respect to the task and the performance required in each situation. Clerical personnel were reported to seek seat heights enabling them to assume a comfortable position of the trunk in relation to the table top.[5] Complaints of posterior thigh discomfort by office employees resulted primarily from shifting body wight to the thighs owing to job requirements, and not so much by their choice of seat height.[5] This evidence suggests that job requirements assume priority over minimizing spinal stress in seat height preferences and selection.

Kirk et al[73] demonstrated that both males and females were able to discriminate accurately between seat heights in unsupported sitting. Seat height discrimination was found to be unrelated to the subject's popliteal height.[73] Le Carpentier[74] observed statistically non-significant correlations between the preferred seat height of easy chairs and the subject's lower leg length. Burandt and Grandjean[5] also reported that body dimensions did not influence the selection of seat heights by office employees.

Wachsler and Learner[70] reported that individuals tended to rate the overall comfort of the seat mainly on the basis of the comfort of their backs and buttocks, while thigh and leg comfort had little relationship to judgements of the overall comfort of a seat. Seats were rated in the same

relative order after five minutes of sitting time as after four hours of sitting.[70]

Observation of spontaneous sitting behavior has shown that the sitter deliberately or unconsciously, assumes a variety of postures.[75] Postures in which the seat gave the least support were infrequent.[75] Branton and Grayson[75] reported that subjects sat with the trunk free from the backrest (unsupported sitting) seven percent of the time during a five hour train trip. Differences in sitting behavior were not related to a misfit of body dimensions and seat dimensions.[71] As there is considerable pressure on the skin and sub-cutaneous tissues under the ischial tuberosities in sitting, ischemia was thought to be a necessary condition for the urge to change posture to become manifest.[71] The relation of a specific posture to comfort was reported to depend, in part, on the degree of muscle relaxation the posture permitted. Branton[71] concluded that sitting behavior may be regarded as an operation that achieves a balance between the needs for physical stability, and for environmental and intrinsic stimulation.

Conclusion

A lifestyle involving prolonged sitting in modern industrial societies has been considered to be a contributory factor in the development of intervertebral

disc pathology and low back pain.[4,13,22] The effect of variations in seat height of the chair on EMG activity of back muscles has not been previously investigated. Minimal IDP and EMG activity of back muscles are desirable in sitting so that mechanical stress on the spine may be reduced to the lowest possible amount.[2,23,24,25,26] However, controversy exists in the literature regarding the optimum seat height of the chair and the ideal sitting posture. Sitting has been shown to move the lumbar spine toward kyphosis as compared to standing, producing a considerable increase in load on the spine as reflected by increased IDP.[1,2,23] Present evidence indicates, that when sitting is used as a work position, the lumbar lordosis should be maintained.[2,3,18,23,58] Support of the lumbar spine has been shown to promote relaxation of the back muscles.[59] However, the backrest of the chair is frequently not used by the occupant of the chair.[2,4,5]

The most important task of the physical therapist, in rehabilitation of patients with low back pain, is to give ergonomic and postural advice based on present knowledge of spinal loading.[6] However, the objective basis for education of patients regarding chair selection in erect unsupported sitting has been incomplete.

CHAPTER III

MATERIALS AND METHODS

Components of the Chair

The standard stenographer's chair used in the study, model 608A, was manufactured by Sunar, a Division of Hauserman Limited, 1 Sunshine Avenue, Waterloo, Ontario, N2J 4K5. The standardized components of the chair were: seat width 42.6 cm; seat depth 30 cm; 5° backward inclination of the seat; uncontoured seat surface; seat thickness 6.2 cm including the rigid wood seat surface, padding and upholstery; adjustable range of seat height 14.1 cm; no arm rests; and the backrest of the chair was removed. The casters of the chair were fixed in position with electrical tape to prevent movement of the chair during testing.

Electromyography

Electromyographic signals were recorded by Beckman miniature biopotential surface electrodes of 7 mm diameter, which had a sensing element of silver-silver chloride.[76] These electrodes have a low source impedance and low

susceptibility to motion artifacts.[76] The gaps under the circular silver discs were filled with electrode jelly, and fixed to the skin surface with double adhesive electrode collars.

The electrodes were connected to the leads of a four channel Beckman EMG system (dynograph recorder), model R612, manufactured by Beckman Instruments, Inc., Electronics Instruments Division, 3900 River Road, Schiller Park, Illinois, 60176. The Beckman dynograph recorder, with pen frequency response to a maximum of 120 Hz and rectilinear pen writing, achieves amplitude linearity of ± 1.25% of full scale.

The first EMG channel was used for the T_{10} level, the second for the L_1 level, the third for the L_3 level, and the fourth for the L_5 level for all subjects. The electrode-lead connectors from the T_{10} and L_1 levels were fixed to each subject's right trunk with Elastoplast adhesive tape, and the L_3, L_5 and ground connectors were fixed to each subject's waist band with masking tape to prevent drag on the electrodes and movement artifacts. The position of the chair in relation to the Beckman EMG machine was kept constant throughout the study.

Direct EMG was recorded throughout the study. Frequency response, in the frequency range of interest, was kept constant for all subjects by use of a 30 Hz low pass

filter setting. Chart speed was 2.5 mm/sec for all subjects. The pre-amplifier multiplier was maintained at ×.1 or a multiplication factor of 10 in all instances. Pre-amplifier gain settings of 0.1 mV/mm and 0.5 mV/mm were used to produce recordings suitable for analysis. A permanent record (electromyogram) was produced from the Beckman dynograph (ink-pen recorder).

Reference Activity and Sitting Positions

1. Erect Unsupported Sitting

The subject's sitting position in the study was with buttocks even with the back of the chair seat, trunk erect, arms hanging, head upright and eyes fixed horizontally. The subject placed her feet on one, two, three or four 37.5 cm by 37.5 cm, 5 cm thickness wooden blocks. The top surface of each block was covered with adhesive floor tile, constituting part of the 5 cm thick. The position of each subject's feet was marked with masking tape, and was kept constant throughout all the test positions. The wooden blocks were placed 5 cm in front of and central to the chairseat for all subjects in all positions.

2. Sitting Positions and Reference Activity

a) Position One was erect unsupported sitting with the seat height of the chair adjusted for each subject such that the thighs were horizontal, lower legs vertical, knee

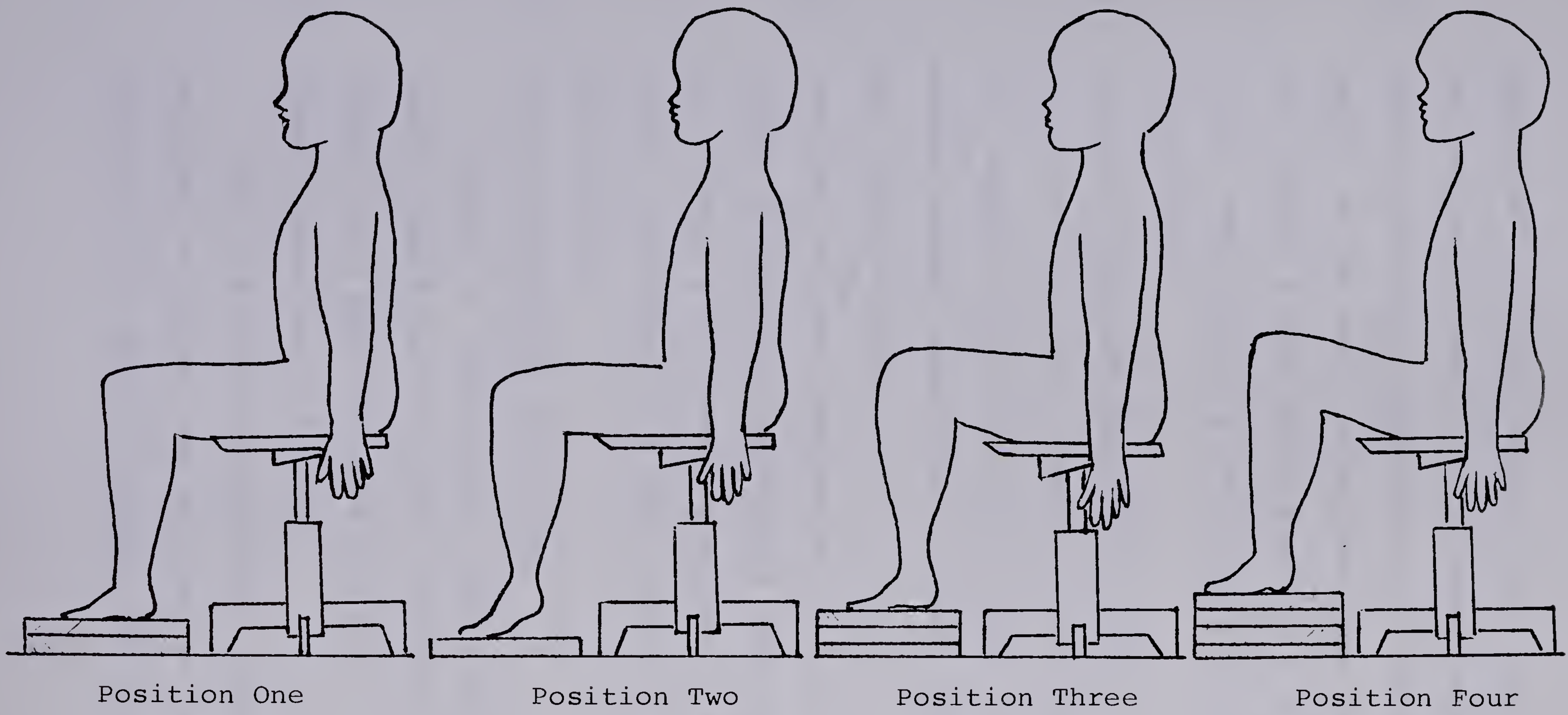

Figure 2. Graphic illustration of Positions One, Two, Three and Four

angles 90°, and the soles of the feet in contact with and resting on two 5 cm thickness wooden blocks.

b) Position Two was unsupported sitting with the seat height of the chair maintained from Position One, and the subject's feet resting on one 5 cm thickness wooden block; resulting in a seat height 5 cm higher than Position One.

c) Position Three was unsupported sitting with the seat height of the chair maintained from Position One, and the subject's feet resting on three 5 cm thickness wooden blocks; resulting in a seat height 5 cm lower than Position One.

d) Position Four was unsupported sitting with the seat height of the chair maintained from Position One, and the subject's feet resting on four 5 cm thickness wooden blocks; resulting in a seat height 10 cm lower than Position One.

e) Flexion-Relaxation in Sitting

Seated in Position One, the subject flexed the trunk forward such that the thorax was resting on the thighs, with head and arms hanging.

f) Spinal Extension in Sitting

From the flexion-relaxation position, the subject extended her spine, and returned to Position One. Subjects were asked to perform the movement at a speed

that was normal and comfortable to them.

The Experimental Procedure

Fifteen female volunteers served as subjects for the study. The two additional female volunteers that participated in the pretest, were excluded from the test group, and from the subject anthropometric data. The subjects were physical therapists who were all engaged in employment of the non-sedentary type, and had no history of chronic low back pain or traumatic back pathology. Subjects ranged in age from 22 to 35 years (mean 28.7 years), in height from 155 to 175 cm (mean 165 cm), and in weight from 49 to 68 kg (mean 59 kg).

Informed consent was obtained from each subject. A copy of the informed consent form is contained in Appendix A. The subjects' weight and height were measured and recorded. The subjects were instructed in the erect unsupported sitting position, and asked to assume it on the experimental chair. The subjects placed their feet on two 5 cm thick wooden blocks. The seat height of the chair was then adjusted so that each subject's position conformed to the criteria established for Position One. The angle of the right knee was checked to ensure that it was 90° using a standard goniometer, with the long axes of the upper and lower legs as points of reference. The position of the

subject's feet was marked with masking tape. Seat height was measured, at the previously marked mid-point of seat depth on the right side of the chair, from the top of the seat to the floor with a meter stick. Measurements of individual characteristics in sitting were trunk height (chair seat to right acromium), knee to hip depth (right knee joint to greater trochanter), and right heel to posterior thigh distance. All measurements, and subsequent testing and data extraction were completed by the author. A summary of subject anthropometric characteristics and reference seat heights are presented in Table I.

The center of the tips of the spinous processes of T_{10}, L_1, L_3 and L_5 were marked on each subject, with a fine tipped felt pen, indicating midline. The skin adjacent to the right of the marked spinous processes was thoroughly cleaned with an alcohol-acetone mixture. Two points 3 cm lateral and parallel to midline, 4 cm apart, and equidistant from the tip of the spinous process were marked to the right of each spinal level. A surface electrode pair, prepared with electrode gel and double adhesive electrode collars, was placed on the previously marked points, 3 cm lateral and parallel to the tip of spinous processes at each level as suggested by Wolf[10] and Andersson et al.[23] Interelectrode distance, measured from center to center, was 4 cm for each electrode pair in all

Table I. Anthropometric characteristics of subjects and reference seat heights

	Individual Characteristics						
				Sitting			
n = 15	Age (years)	Weight (kg)	Height (cm)	Trunk Height (cm)	Knee-Hip Depth (cm)	Heel-Posterior Thigh distance (cm)	Reference Seat Heights (Position One) (cm)
Mean	28.7	59	165.04	53.9	44.1	42.1	39.82
Standard Deviation	4.43	5.80	5.58	2.50	2.39	1.91	1.55
Range	22 - 35	48.89 - 67.6	155.35 - 174.7	48 - 58.6	41.2 - 49.2	38.3 - 45.3	36.7 - 41.5

instances. The ground electrode was placed on the left lumbar region, after thorough cleaning of the skin. All the surface electrodes and their adhesive collars were covered with Elastoplast adhesive tape to provide pressure at the electrode sites. The location of the surface electrode pairs is illustrated in Figure 3.

The electrodes were connected to a four channel Beckman EMG system as previously described. The subjects were again instructed in the nature of the erect unsupported sitting position, and in the sequence of the test procedure. Subjects were given one practise of the Position One, flexion, flexion-relaxation and extension in sitting sequence. Subjects were asked to relax as much as possible during the flexion-relaxation phase.

Electromyographic recording was commenced, with each subject seated in Position One. The electromyogram was checked visually, and pre-amplifier gain adjustments made as necessary to yield a recording suitable for analysis. The subject was then given a second practise of the Position One, flexion, flexion-relaxation and extension in sitting sequence which was recorded on the chart. The subject's third performance of the sequence was recorded, and used for purposes of analysis of the flexion-relaxation position. Each subject then performed one additional sequence to provide a total of three records of spinal extension in

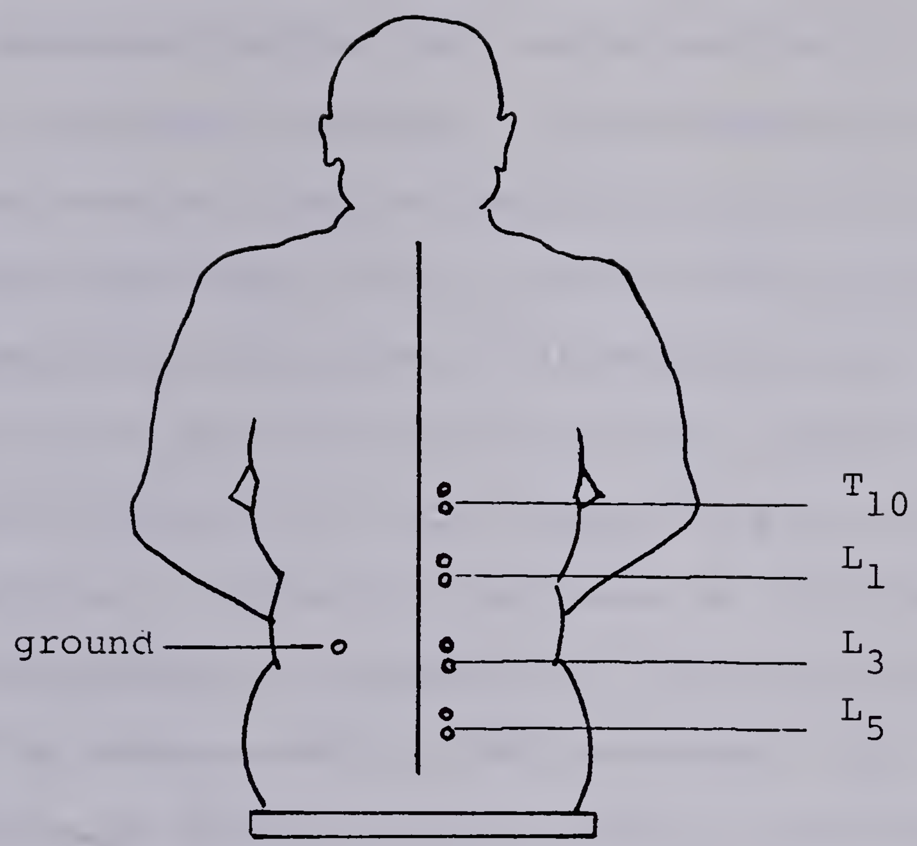

Figure 3. Location of surface electrode pairs

sitting.

The time sequence for the test was determined by a pretest, using two female subjects. Electromyographic activity of back muscles from the right T_{10}, L_1, L_3 and L_5 spinal levels was monitored at one, two and three minutes following the subject's being seated in Position One. A consistent pattern of EMG activity at all four spinal levels after one minute indicated that the subject had settled in the sitting position. One minute was taken as the time required for the subject to accommodate to each sitting position prior to commencement of EMG recording. The two and three minute time periods were excluded on the basis of the possibility of introducing the fatigue artifact as the result of prolonged test periods.[35,46]

Electromyographic recording was commenced after each subject had maintained each test position for a period of one minute. Three EMG recordings, each of 20 sec duration, interspersed with two 20 second time periods, were made for each of the four positions for each subject. Position One was administered first, as Positions Two, Three and Four were established in reference to the seat height obtained in Position One for each subject. The sequence for administration of Positions Two, Three and Four was randomly assigned to each subject using a random number table.[77] Between test positions, the subjects were told to relax, and

the number of wooden blocks supporting the feet required for next test position were situated. Subjects were then asked to stand for a period of 30 seconds before assuming the next test position. Plate 1 illustrates the experimental setting. The sequence of events is described in Figure 4. Following the completion of EMG recording in the four test positions, each subject was asked to rank the four test positions with respect to comfort. A scale of one to four was used, with one being the most comfortable and four being the least comfortable.

Subject number ten was retested, two hours after the test. The EMG surface electrode pairs were removed after the test, and reapplied for retesting. The retest experimental procedure was identical to the test procedure described previously. Consistent with test procedure, a different sequence for administration of Positions Two, Three and Four, was assigned to the retest from the random number table.

Data Presentation and Analysis

Subject individual measurements, equivalent seat heights in the four test positions, and the subjective assessment of comfort were recorded for each subject. Data collection forms are contained in Appendix B.

Plate 1. The experimental setting

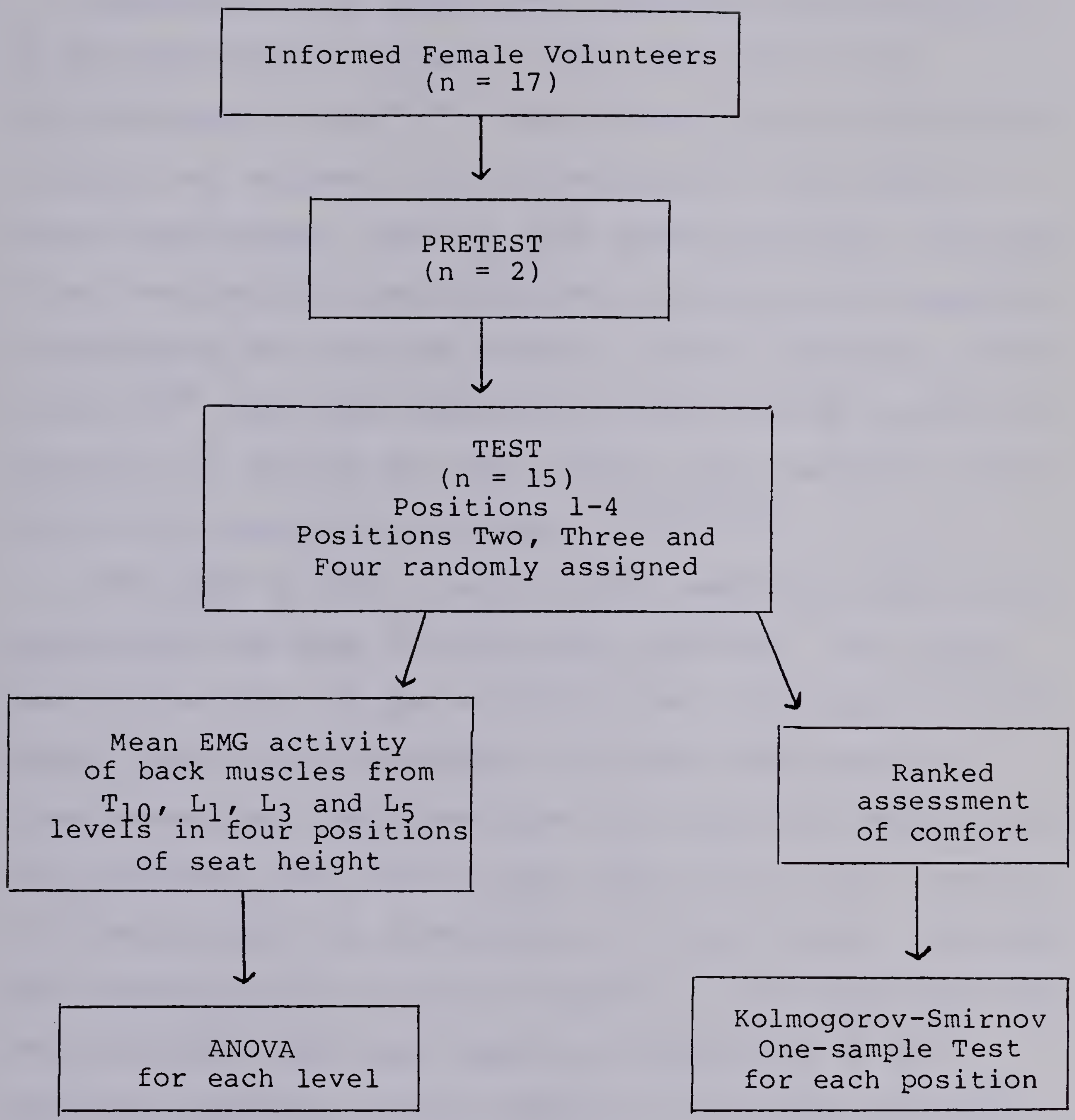

Figure 4. Flow diagram of study conducted

Analysis of the direct EMG recordings was carried out by the measurement of peak to peak amplitude of the electromyogram in mm.[34,45] The EKG artifact was identified visually and excluded from the analysis.[45] The mean of three measurements, taken at five second intervals, from the flexion-relaxation electromyogram, was used as the baseline interference for each EMG channel, and was assigned a value of 0%.[36,45] The mean amplitude of the three EMG records of extension in sitting for each channel, was assigned a value of 100% for purposes of analysis.[34,36,48,49]

The mean of four, 5 sec interval amplitude measurements were taken from each 20 second EMG recording. The grand mean of the three 20 sec recordings was calculated for each spinal level in each position. The mean EMG baseline interference was subtracted from the grand mean amplitude of each position, and from the mean amplitude of the extension in sitting value for each channel or spinal level. The mean EMG activity of back muscles recorded in Positions One, Two, Three and Four were then taken as a proportion of the reference activity (spinal extension in sitting) for each channel,[34,36,48,49] to yield a percent score for each of T_{10}, L_1, L_3 and L_5 spinal levels in four test positions for each subject. The EMG Amplitude Table for data collection is contained in Appendix B.

A computer conducted analysis of variance, one way

classification was performed for each spinal level (T_{10}, L_1, L_3, L_5).[78] A 0.05 level of significance was established for all statistical testing. A Pearson Product Moment Correlation Coefficient was performed between the subjects' posterior thigh to heel measurements and the reference seat height (Position One).[79] The Kolmogorov-Smirnov One-Sample Test for each test position was used to evaluate data obtained from the subjective assessment of comfort.[80] Absolute differences in the amplitudes and in the percent scores were obtained from each position of the test/retest data, and the mean differences were calculated. The tolerated difference was established as 1 mm or 5 percent.

CHAPTER IV

RESULTS

The major purpose of the study was to determine if EMG activity of back muscles at the T_{10}, L_1, L_3 and L_5 spinal levels in erect unsupported sitting differed between the four positions of seat height. The reference seat height (Position One) for each subject was established by the subject position of thighs horizontal, lower legs vertical, knee angles 90°, and feet supported. Position Two provided the equivalence of a seat height of 5 cm higher than Position One. Positions Three and Four provided the equivalence of seat heights 5 cm and 10 cm lower than Position One, respectively.

Test/retest raw data for each of the four spinal levels, may be found in Appendix C. Mean absolute differences in the test/retest electromyogram expressed in mm and percent scores, are presented in Table II. Figure 5 demonstrates the test/retest electromyogram from the T_{10} and L_1 levels for Position One.

Electromyographic activity of back muscles from surface electrode pairs at the T_{10}, L_1, L_3 and L_5 levels, in

Table II. Absolute differences in EMG test/retest data for one subject with surface electrode pairs reapplied two hours after the test

MEAN DIFFERENCES
($\overline{X}D$)

T_{10}			L_1		
Position	mm	%	Position	mm	%
1	0.14	1.3	1	0.08	8.4
2	0.52	4.4	2	0.11	9.8
3	1.09	8.0	3	0.33	5.0
4	1.25	9.2	4	0.72	3.1
$\overline{X}D$ T_{10}	0.75	5.7	$\overline{X}D$ L_1	0.31	6.6

L_3			L_5		
Position	mm	%	Position	mm	%
1	1.81	4.4	1	0.17	2.8
2	0.96	0.4	2	0.05	2.8
3	1.64	3.3	3	0.07	6.1
4	1.4	2.2	4	0.06	4.9
$\overline{X}D$ L_3	1.45	2.6	$\overline{X}D$ L_5	0.09	4.2

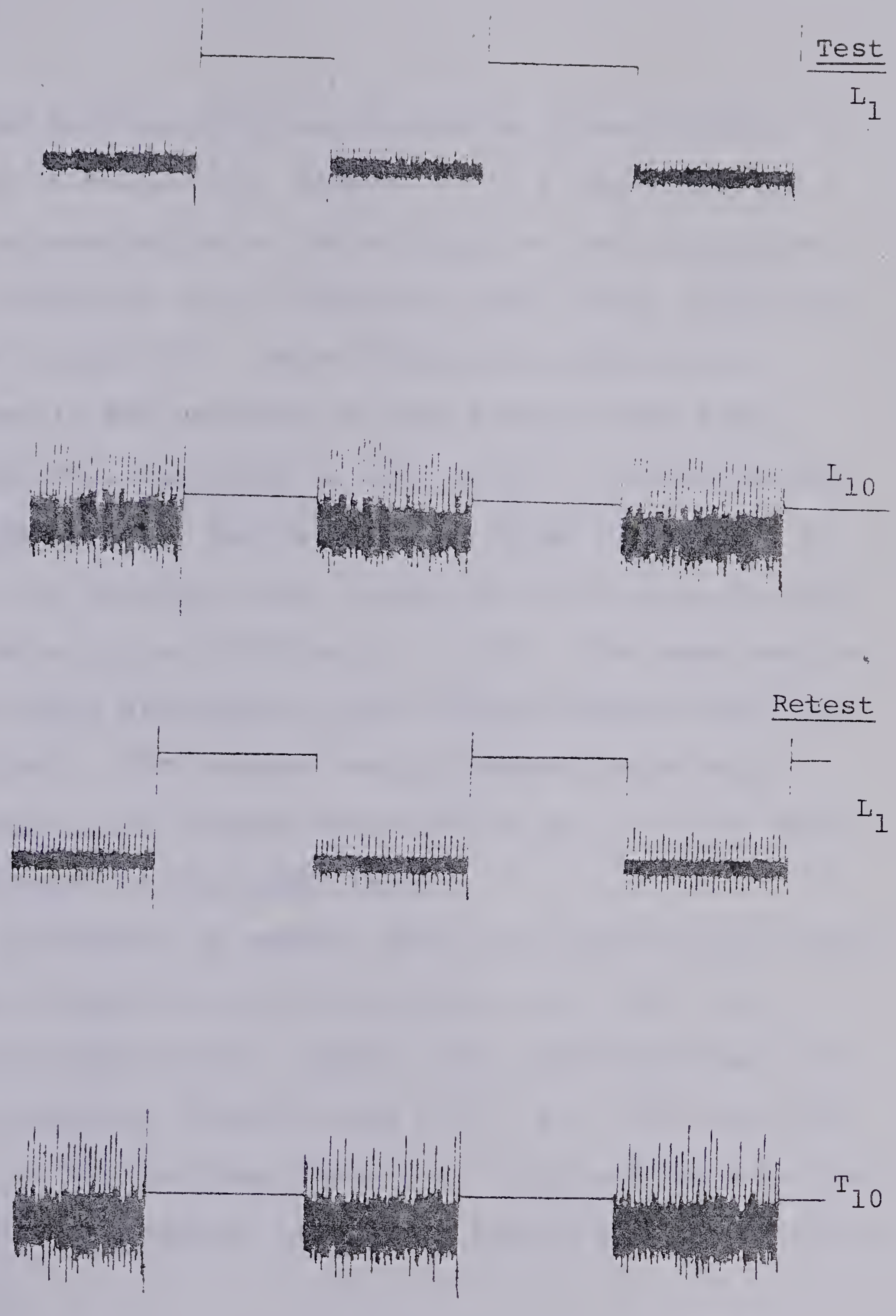

Figure 5. The test/retest electromyogram from T_{10} and L_1 levels for Position One

unsupported sitting with four positions of seat height is summarized in Table III. Figures 6, 7, 8 and 9 provide graphic representation of EMG activity at the four spinal levels. Summaries of the ANOVA for each spinal level are presented in Table IV. No statistically significant differences in EMG activity of back muscles were found between the four positions of seat height, at each of the four spinal levels. Raw data may be found in Appendix D.

The mean reference seat height (Position One) for the fifteen subjects was 39.82 cm ($s = 1.55$). The mean heel to posterior thigh distance for the fifteen subjects was 42.1 cm ($s = 1.91$). The Pearson Product Moment Correlation Coefficient for the paired measurements was $r = 0.92$ which was significant at the 0.005 level.

The assessment of comfort data was tested statistically with the Kolmogorov-Smirnov One-Sample Test, for each position of seat height. Results were non-significant for all four positions (Position One $0.10 < p < 0.15$, Position Two $p = > 0.20$, Position Three $p = > 0.20$ and Position Four $P = > 0.20$). Assessment of comfort raw data is contained in Appendix D.

Table III. EMG activity of back muscles expressed as a percentage of a standard stress, at the T_{10}, L_1, L_3, and L_5 levels in erect unsupported sitting with four positions of seat height

n = 15 Level		Position One	Position Two	Position Three	Position Four
T_{10}	$\bar{X}$	20.5	19.5	18.9	18.8
	s	13.1	15.2	15.8	16.3
L_1	$\bar{X}$	11.7	11.7	11.5	10.6
	s	6.7	8.4	7.5	6.5
L_3	$\bar{X}$	6.5	6.1	6.0	6.2
	s	3.0	3.2	2.8	3.0
L_5	$\bar{X}$	4.5	4.2	4.4	5.6
	s	2.7	2.4	2.5	3.7

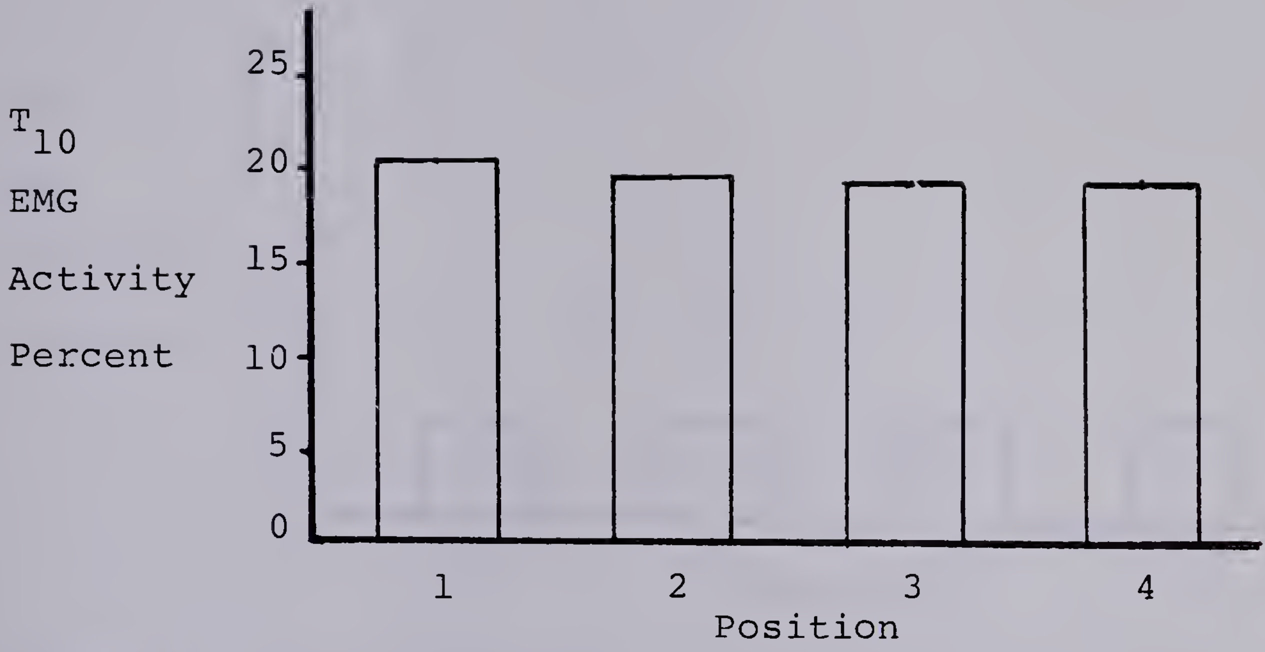

Figure 6. Electromyographic activity of back muscles at T_{10} in erect unsupported sitting with four positions of seat height

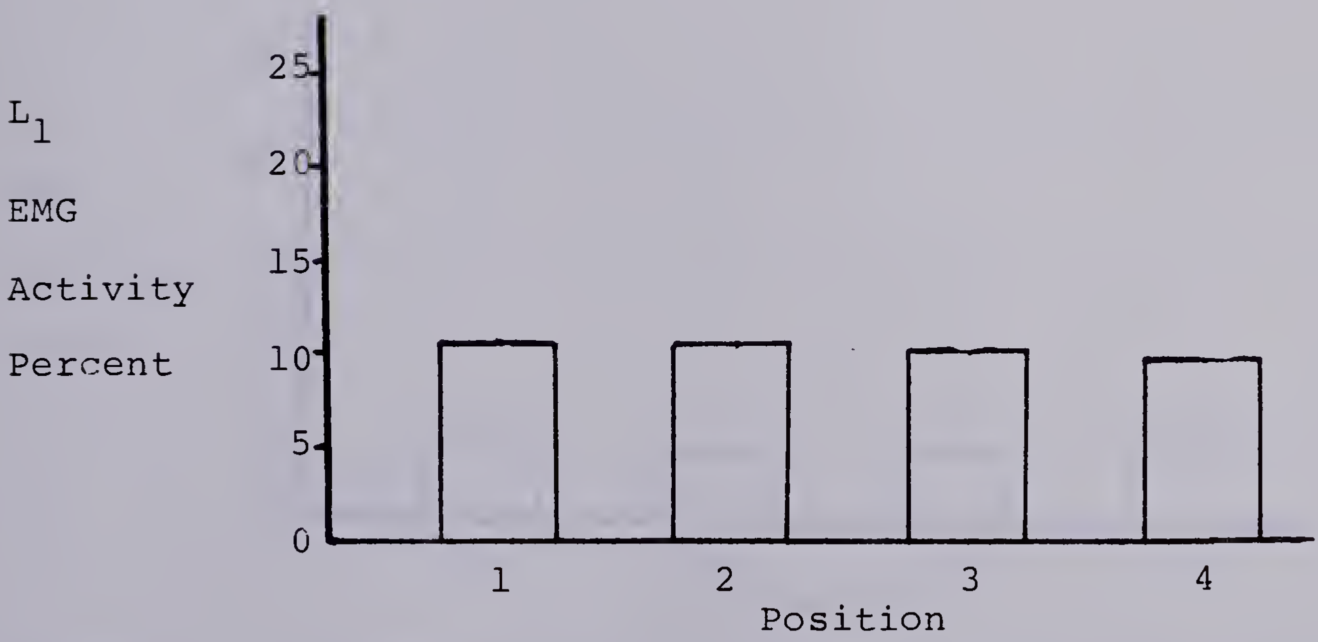

Figure 7. Electromyographic activity of back muscles at L_1 in erect unsupported sitting with four positions of seat height

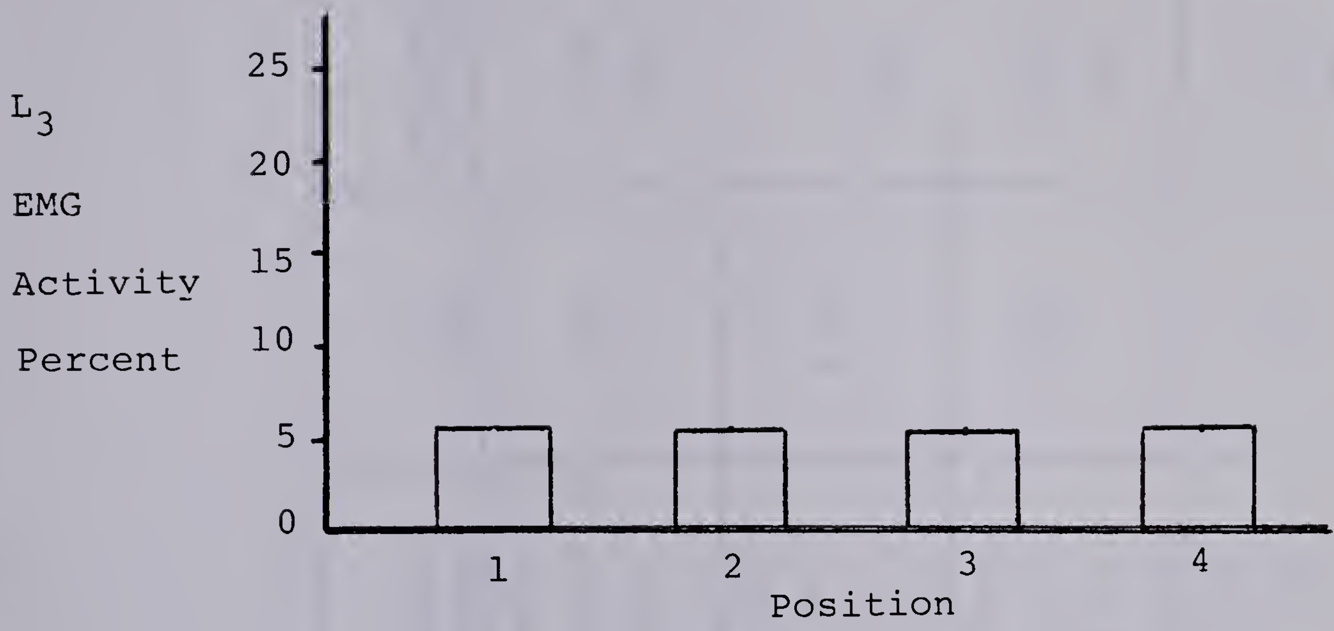

Figure 8. Electromyographic activity of back muscles at L_3 in erect unsupported sitting with four positions of seat height

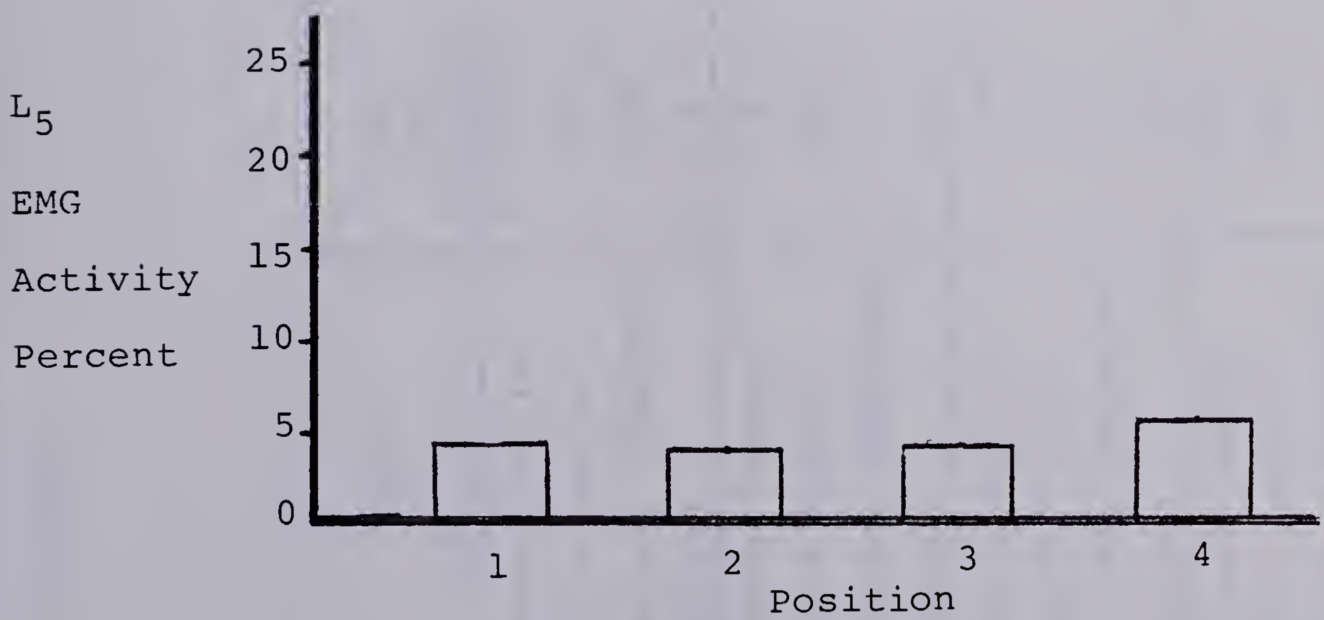

Figure 9. Electromyographic activity of back muscles at L_5 in erect unsupported sitting with four positions of seat height

Table IV. ANOVA summaries, EMG activity at T_{10}, L_1, L_3 and L_5 with four positions of seat height

n = 15 LEVEL	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probability $p < 0.05$
T_{10}	Between People	0.12	14	0.89	0.91	0.44 NS
	Within People	0.46	45	0.10		
	Repeated measures	0.28	3	0.94		
	Residual	0.43	42	0.10		
L_1	Between People	0.25	14	0.18	0.40	0.76 NS
	Within People	0.45	45	1.00		
	Repeated measures	0.12	3	0.41		
	Residual	0.44	42	0.10		
L_3	Between People	0.36	14	0.26	0.25	0.86 NS
	Within People	0.12	45	0.27		
	Repeated measures	0.21	3	0.71		
	Residual	0.12	42	0.29		
L_5	Between People	0.28	14	0.20	0.41	0.25 NS
	Within People	0.18	45	0.40		
	Repeated measures	0.17	3	0.55		
	Residual	0.16	42	0.39		

CHAPTER V

DISCUSSION

Erector spinae muscle activity has been shown to be a reliable index of spinal stress.[28,29,76] The conditions of the present study were such that a linear relationship between the electromyogram and muscle tension was considered to have existed, in keeping with the criteria set forth by Ralston[37], and Grossman and Weiner.[39] Test/retest data was consistent with the report of Ralston[37], in that the results of an experiment may not be reproduced precisely if the electrodes have been removed from the subject and reapplied for retesting. Absolute differences in test/retest EMG activity of back muscles may be accounted for, in part, by differences in skin preparation, and the two hour interval in time between the tests.[36] Differences in test/retest data may also be attributed, in part, to the standard error of measurement defined by Ferguson[79] as the standard deviation of scores an individual might be expected to obtain on a large number of randomly parallel test forms. The two hour interval between tests was considered to have

[illegible]

been sufficient to discount changes in the EMG amplitude due to fatigue. As the time in each test position was brief (2.67 minutes), the effect of practise on the retest EMG amplitude was considered to be negligible.

The largest test/retest differences in EMG activity of back muscles occurred at the T_{10} and L_1 levels. Hilton et al[81] and Jayson[82] reported that Schmorl's nodes and vertebral fractures due to both violent trauma and osteoporosis occur most frequently in the dorsolumbar region. The T_{10}-L_1 region was considered to be relatively susceptible to mechanical stress.[81,82] Basmajian[42] reported that the susceptibility of thoraco-lumbar region to trauma was the result of the rather abrupt transition from the more mobile lumbar vertebrae to the less mobile thoracic vertebrae. Unsupported sitting has been reported to produce significant stress on the thoraco-lumbar spine as compared to standing or sitting with the trunk supported.[1,23,33] Posterior rotation of the pelvis has been shown to occur in unsupported sitting, as compared to standing, which is accompanied by flattening of the lumbar lordosis.[8,9] The line of gravity, ventral to the lumbar spine in standing, shifts further ventrally in unsupported sitting, creating a longer lever arm for the force exerted by the weight of the trunk.[56] The forward bending moments acting on the trunk in unsupported sitting must be counterbalanced by ligament

forces and back muscle forces.[56] Significant muscle activity (18.8 to 20.5% at T_{10} and 10.6 to 11.7% of extensor effort at T_{10} and L_1, respectively) was required to balance the trunk against gravitational forces in erect unsupported sitting in the present study. The sensitivity of the dorsolumbar region to mechanical stress, combined with the relatively high stress produced in erect unsupported sitting may, in part, account for the relatively greater test/retest differences that occurred at the T_{10} and L_1 levels. The contributions of the trapezius and latissimus dorsi muscles to the electromyogram, both of which do not function primarily as postural muscles[41,42], may also have attributed to the test/retest differences that occurred at the T_{10} level.

The forces exerted by the erector spinae group of muscles in erect unsupported sitting have been reported to function in stabilizing the trunk against gravitational forces.[50,51] The placement of EMG surface electrode pairs in the current study was similar to the electrode positions reported by Wolf et al[10] and Andersson et al.[23] Electrode placement 3 cm lateral and parallel to the tips of the spinous processes at the T_{10}, L_1, L_3 and L_5 levels was reported to monitor activity of the longissimus and multifidus muscles.[10,23]

Electromyographic activity of back muscles, at each of the T_{10}, L_1, L_3 and L_5 levels, in the current study was

[illegible]

[illegible]

[illegible]

[illegible]

consistant with the hypothesis that there was no difference between the four positions of seat height. The erect unsupported sitting position in the present study conforms to the straight unsupported sitting position described by Andersson et al.[23,33,41] When the straight unsupported sitting position was compared to the relaxed unsupported sitting position, IDP decreased but EMG activity of back muscles remained unchanged.[23] The posture of the lumbar spine was reported to be straight or in slight lordosis in straight unsupported sitting, as compared to straight or in slight kyphosis in relaxed unsupported sitting.[23,33] In the present study, subjects were instructed to maintain an erect unsupported sitting posture during each of the four test positions. The line of gravity acting on the trunk, and the posture of the lumbar spine were likely to have changed only slightly or remained unaltered between the four test positions. Minor changes in the posture of the lumbar spine between test positions were considered to be counteracted by erector spinae muscle forces required to balance the trunk in unsupported sitting. Nachemson[83] stated that the resistance to load that the lumbar motion segments can generate passively is overwhelmed by the load producing capabilities of the trunk musculature. Electromyographic activity of back muscles in the present study was similar in each of the four positions of seat height, and relatively

high spinal stress was maintained in each test position.

Andersson et al[23,33] reported that when subjects were seated in the straight unsupported sitting position, the lumbar spine was held straight or in slight lordosis. Similar between subject variations in lumbar posture were likely to have occurred in the present study, and may, in part, account for high between subject variation in EMG activity of erector spinae. Andersson et al[41] reported considerable variation in EMG activity of back muscles between subjects, in both the relaxed and straight unsupported sitting positions. Frankel and Nordin[56] also reported that the level of postural activity in different muscle groups varies considerably among individuals. The magnitude of habitual kyphosis and lordosis of the lumbar spine has been reported to influence the posture an individual assumes in sitting[2,56], and would therefore, also be expected to contribute to between subject variation in EMG activity of back muscles in unsupported sitting.

Results of statistical testing of the assessment of comfort data were consistent with the hypothesis that there was no difference in preferences among the four positions of seat height. Wachsler and Learner[70] reported that individuals tended to rate overall comfort of the seat mainly on the basis of the comfort of their backs and buttocks. Branton[71] reported that the relation of a

specific sitting posture to comfort depended, in part, on the degree of muscle relaxation the posture permitted. Electromyographic activity of back muscles was similar between the four positions of seat height in the present study. Assessment of comfort findings were, therefore, in agreement with reports by previous authors, and with the main finding of the present study.

As the 15 subjects in the study collectively exhibited no difference in preferences between the four positions of seat height, it was concluded that sitting comfort was similar for the four positions of seat height examined. The four unsupported sitting positions, in the present study, produced similar spinal stress as evidenced by similar EMG activity of back muscles at each of the four spinal levels, for each of the four positions of seat height. Sitting comfort may be associated with the magnitude of spinal stress produced in erect unsupported sitting. Support for this interpretation is given by the report of Branton and Grayson[75] who demonstrated that subjects assumed the unsupported sitting position only 7 percent of the time during a five hour train trip. Postures in which the seat gave the least support were reported to be infrequent,[75] and would represent situations of relatively greater spinal stress. Furthermore, Kirk et al[73] demonstrated that individuals are able to discriminate accurately between seat

heights in erect unsupported sitting. However, as sitting comfort should be considered with respect to the task and the performance required in each situation,[71,72] job requirements may override sitting comfort in the work situation.

The reference seat height obtained for each subject, in the present study, was governed by the standardized criteria established for Position One. A correlation coefficient of $r = 0.92$ ($p < 0.005$) was found between the reference seat heights, and the posterior thigh to heel measurements. Seat height preferences were reported to be unrelated to the subject's lower leg length.[5,74]

CHAPTER VI

CONCLUSIONS

With the data available from the present study, the following conclusions were made:

1. Electromyographic activity of the erector spinae group of muscles at the T_{10}, L_1, L_3, and L_5 levels, in erect unsupported sitting, was similar between the four positions of seat height studied. The 15 cm range of seat height examined was established in reference to the subject position of thighs horizontal, lower legs vertical, knee angles 90° and feet supported (Position One). Position Two was with a seat height of 5 cm higher than Position One. Positions Three and Four were 5 cm lower and 10 cm lower than Position One, respectively. As EMG activity of back muscles is considered to be a reliable index of mechanical stress acting on the spine, spinal stress in erect unsupported sitting, within the limitations and delimitations imposed on the present study, was similar between the four positions of seat height examined.

2. The 15 subjects in the present study demonstrated no significant preferences among the four positions of seat height. It was concluded that sitting comfort was similar for the four positions of seat height examined. Electromyographic activity of back muscles, and hence spinal stress were also similar for the four unsupported sitting positions. Sitting comfort may, therefore, be associated with the magnitude of spinal stress produced in erect unsupported sitting.

Recommendations

The major recommendations that can be made from the current study are as follows:

1. A similar investigation be conducted to determine the effects of varying seat heights on EMG activity of back muscles during sitting with backrest support.
2. A similar study be carried out to determine the effects of varying seat heights on EMG activity of back muscles during relaxed unsupported sitting.
3. Further study of the relationship between the level of spinal stress in sitting and sitting comfort.
4. Establishment of the nature of the relationship between habitual spinal postures in sitting and seat height preferences.

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APPENDIX A

Informed Consent Form

Department of Physical Therapy
Faculty of Rehabilitation Medicine
University of Alberta
June, 1982

INFORMED CONSENT FORM FOR INVESTIGATIVE STUDY

Electromyographic Activity of Back Muscles During Erect Unsupported Sitting with Varying Seat Heights

Outline of Procedures (retained by subject)

The purpose of the study is to determine the optimum seat height of chair, and its effect on the sitting posture of an individual. The entire procedure will require an hour of time, in one session. Your height and weight will first be measured. Knee to hip depth, trunk height, and heel to thigh distance will then be measured in sitting. Four pairs of electromyographic electrodes will then be placed on the skin surface of your right low back region, attached by adhesive collars and adhesive tape.

You will be asked to perform three repetitions of forward bending in sitting. Back muscle activity will then be monitored over a period of one minute as you sit on a stenographer's chair. Three further one minute periods of measurement of back muscle activity will be carried out, with three alterations of seat height of the chair. The testing procedure will then be completed, and the electrodes and adhesive tape will be removed.

The test procedure does not involve any abnormal risks. Many persons in our society commonly spend much of the day sitting. Information gained from this study is expected to facilitate chair selection, particularly for patients with low back problems, and persons involved in occupations requiring prolonged sitting.

You may withdraw from participation as a subject in this investigation at any time. An effort will be made to answer any questions you may have concerning the testing procedures or other aspects of the project.

All records will be held in confidence. The report of the study will include averages and trends for subjects as a group without identification of individuals.

Department of Physical Therapy
Faculty of Rehabilitation Medicine
University of Alberta
June, 1982

INFORMED CONSENT FOR INVESTIGATIVE STUDY

Electromyographic Activity of Back Muscles
During Erect Unsupported Sitting with
Varying Seat Heights

Subject Consent (retained by investigator)

I ______________________________________ agree to
(Name - please print)
participate as a subject in the study entitled "Electromyographic Activity of Back Muscles During Erect Unsupported Sitting with Varying Seat Heights" to be conducted by Conne Robertshaw. The nature of this study has been explained to me, and I have been advised that I may withdraw from participation at any time.

Date: ______________________ ______________________________
Subject's Signature

APPENDIX B

Data Acquisition Forms

Seat heights

Subject: ______________________ Date: __________

Position	Seat Height (cm)
1	
2	
3	
4	

Subject individual characteristics.

Subject: ______________________________ Date: __________

Age (years)	
Height (cm)	
Weight (kg)	

IN SITTING

Trunk height (cm) (chair seat to right acromium)	
Knee to hip depth (cm) (right knee joint to greater trocanter)	
Right heel to posterior thigh distance (cm)	

Assessment of Comfort

Subject: ______________________________ Date: ________

Scale: Most comfortable 1 2 3 4 Least comfortable

$\longrightarrow$

Position One __________

Position Two __________

Position Three __________

Position Four __________

EMG AMPLITUDE TABLE					
Subject:					
Level	EMG Baseline 0%				
	1	2	3	4	$\overline{X}$
T_{10}					
L_1					
L_3					
L_5					

Level	EMG Extension 100%				
	1	2	3	4	$\overline{X}$
T_{10}					
L_1					
L_3					
L_5					

Position One

Level	Session 1					Session 2					Session 3					
	1	2	3	4	$\overline{X}$	1	2	3	4	$\overline{X}$	1	2	3	4	$\overline{X}$	G$\overline{X}$
T_{10}																
L_1																
L_3																
L_5																

Position Two

Level	Session 1					Session 2					Session 3					
	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$	$G\bar{X}$
T_{10}																
L_1																
L_3																
L_5																

Position Three

Level	Session 1					Session 2					Session 3					
	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$	$G\bar{X}$
T_{10}																
L_1																
L_3																
L_5																

Position Four

Level	Session 1					Session 2					Session 3					
	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$	$G\bar{X}$
T_{10}																
L_1																
L_3																
L_5																

APPENDIX C

Test/Retest Raw Data

Test/Retest Raw Data for T_{10} Level

for subject #10 with electrodes reapplied two hours after the test. Sessions 1, 2 and 3 each represent a 20 second direct EMG recording. Millimeter and percent scores represent EMG activity, and D represents the absolute difference in test/retest values.

	Test (x)	Retest (y)
Channel	1	1
Pre-amplifier multiplier	×.1	×.1
Pre-amplifier gain	.2	.2
Filter	30 Hz	30 Hz
Chart speed	2.5 mm/sec	2.5 mm/sec
Testing sequence	1, 3, 2, 4	1, 2, 3, 4
EMG baseline (0%)	1.8 mm	1.83 mm
Spinal extension (100%)	17.07 mm	16.43 mm

Position One						
	mm			%		
Session	x	y	D	x	y	D
1	5.90	6.00	0.10	26.9	28.6	1.7
2	6.00	6.18	0.18	27.5	27.8	0.3
3	6.00	6.13	0.13	27.5	29.5	2.0
$\overline{X}$			0.14			1.3

Position Two						
	mm			%		
Session	x	y	D	x	y	D
1	5.28	5.78	0.50	22.8	27.05	4.3
2	5.35	5.75	0.40	23.2	26.8	3.6
3	5.20	5.85	0.65	22.3	27.5	5.2
$\overline{X}$			0.52			4.4

Position Three						
	mm			%		
Session	x	y	D	x	y	D
1	4.70	5.80	1.10	19.0	27.2	8.2
2	4.75	5.90	1.15	19.3	27.9	8.6
3	4.85	5.88	1.03	20.0	27.3	7.3
$\overline{X}$			1.09			8.0

Position Four						
	mm			%		
Session	x	y	D	x	y	D
1	4.98	6.15	1.17	20.8	29.6	8.8
2	4.95	6.28	1.33	20.6	30.1	9.5
3	5.00	6.25	1.25	21.0	30.3	9.3
$\overline{X}$			1.25			9.2

Test/Retest Raw Data for L_1 Level

for subject #10 with electrodes reapplied two hours after the test. Sessions 1, 2 and 3 each represent a 20 second direct EMG recording. Millimeter and percent scores represent EMG activity, and D represents the absolute difference in test/retest values.

	Test (x)	Retest (y)
Channel	2	2
Pre-amplifier multiplier	×.1	×.1
Pre-amplifier gain	.2	.2
Filter	30 Hz	30 Hz
Chart speed	2.5 mm/sec	2.5 mm/sec
Testing sequence	1, 3, 2, 4	1, 2, 3, 4
EMG baseline (0%)	0.93 mm	1.38 mm
Spinal extension (100%)	11.53 mm	19.67 mm

Position One						
	mm			%		
Session	x	y	D	x	y	D
1	2.40	2.30	0.10	13.9	5.0	8.9
2	2.48	2.45	0.03	14.6	5.9	8.7
3	2.40	2.50	0.10	13.9	6.1	7.8
$\overline{X}$			0.08			8.5

Position Two						
Session	mm			%		
	x	y	D	x	y	D
1	2.70	2.60	0.10	16.7	6.8	9.9
2	2.60	2.58	0.02	15.8	6.6	9.2
3	2.65	2.45	0.20	16.2	5.9	10.3
$\overline{X}$			0.11			9.8

Position Three						
Session	mm			%		
	x	y	D	x	y	D
1	2.05	2.38	0.33	10.6	5.5	5.1
2	2.00	2.28	0.28	10.1	4.9	5.2
3	1.98	2.35	0.37	9.9	5.3	4.6
$\overline{X}$			0.33			5.0

Position Four						
Session	mm			%		
	x	y	D	x	y	D
1	2.13	2.70	0.57	11.3	7.2	4.1
2	2.08	2.83	0.75	10.8	7.9	2.9
3	2.05	2.90	0.85	10.6	8.3	2.3
$\overline{X}$			0.72			3.1

Test/Retest Raw Data for L_3 Level

for subject #10 with electrodes reapplied two hours after the test. Sessions 1, 2 and 3 each represent a 20 second direct EMG recording. Millimeter and percent scores represent EMG activity, and D represents the absolute difference in test/retest values.

	Test (x)	Retest (y)
Channel	3	3
Pre-amplifier multiplier	×.1	×.1
Pre-amplifier gain	.2	.2
Filter	30 Hz	30 Hz
Chart speed	2.5 mm/sec	2.5 mm/sec
Testing sequence	1, 3, 2, 4	1, 2, 3, 4
EMG basline (0%)	1.08 mm	1.68 mm
Spinal extension (100%)	22.03 mm	25.53 mm

Position One						
	mm			%		
Session	x	y	D	x	y	D
1	2.15	3.88	1.73	5.1	9.2	4.1
2	2.03	3.90	1.87	4.5	9.3	4.5
3	2.08	3.90	1.82	4.8	9.3	4.5
$\bar{X}$			1.81			4.4

Position Two						
	mm			%		
Session	x	y	D	x	y	D
1	3.05	4.00	0.95	9.4	9.7	0.3
2	3.00	4.05	1.05	9.2	9.9	0.7
3	3.13	4.00	0.87	9.8	9.7	0.1
$\bar{X}$			0.96			0.4

Position Three						
	mm			%		
Session	x	y	D	x	y	D
1	2.78	4.48	1.70	8.1	11.7	3.6
2	2.75	4.40	1.65	8.0	11.4	3.4
3	2.88	4.45	1.57	8.6	11.6	3.0
$\bar{X}$			1.64			3.3

Position Four						
	mm			%		
Session	x	y	D	x	y	D
1	3.13	4.23	1.10	9.8	10.7	0.9
2	3.05	4.58	1.53	9.4	12.2	2.8
3	2.98	4.55	1.57	9.1	12.0	2.9
$\bar{X}$			1.40			2.2

Test/Retest Raw Data for L_5 Level

for subject #10 with electrodes reapplied two hours after the test. Sessions 1, 2 and 3 each represent a 20 second direct EMG recording. Millimeter and percent scores represent EMG activity, and D represents the absolute difference in test/retest values.

	Test (x)	Retest (y)
Channel	4	4
Pre-amplifier multiplier	×.1	×.1
*Pre-amplifier gain	.5	.2
Filter	30 Hz	30 Hz
Chart speed	2.5 mm/sec	2.5 mm/sec
Testing sequence	1, 3, 2, 4	1, 2, 3, 4
EMG baseline (0%)	0.9 mm	1.0 mm
Spinal extension (100%)	3.5 mm	19.63 mm

*x mm values multiplied by .5, y mm values multiplied by .2.

Position One						
	mm			%		
Session	x	y	D	x	y	D
1	0.55	0.39	0.16	7.7	5.1	2.6
2	0.55	0.37	0.18	7.7	4.5	3.2
3	0.55	0.39	0.16	7.7	5.0	2.7
$\bar{X}$			0.17			2.8

Position Two						
Session	mm			%		
	x	y	D	x	y	D
1	0.50	0.45	0.05	3.8	6.7	2.9
2	0.50	0.45	0.05	3.8	6.6	2.8
3	0.50	0.44	0.06	3.8	6.4	2.6
$\bar{X}$			0.05			2.8

Position Three						
Session	mm			%		
	x	y	D	x	y	D
1	0.50	0.56	0.06	3.8	9.7	5.9
2	0.50	0.58	0.08	3.8	10.1	6.3
3	0.50	0.57	0.07	3.8	9.8	6.0
$\bar{X}$			0.07			6.1

Position Four						
Session	mm			%		
	x	y	D	x	y	D
1	0.65	0.59	0.06	15.4	10.5	4.9
2	0.65	0.59	0.06	15.4	10.5	4.9
3	0.65	0.59	0.06	15.4	10.5	4.9
$\bar{X}$			0.06			4.9

APPENDIX D

Raw Data

EMG Activity of Back Muscles at the T_{10} Level, expressed as a percentage of a standard stress, for 15 subjects with four positions of seat height.

Subject	Position 1	2	3	4
01	22.1	18.8	22.3	16.8
02	22.8	26.1	30.8	29.9
03	21.0	20.7	15.5	13.4
04	13.7	13.2	16.4	15.5
05	17.8	7.1	5.1	7.4
06	20.9	18.5	18.0	25.9
07	7.1	7.0	6.4	5.7
08	62.7	69.5	69.9	71.8
09	5.6	4.2	3.1	2.7
10	27.3	22.8	19.4	20.8
11	17.3	13.5	10.8	13.4
12	18.1	14.8	17.4	12.9
13	20.6	19.7	16.4	20.8
14	16.9	23.1	19.9	12.1
15	11.5	13.4	12.1	13.4

EMG Activity of Back Muscles at the L_1 Level, expressed as a percentage of a standard stress, for 15 subjects with four positions of seat height.

	Position			
Subject	1	2	3	4
01	18.0	8.5	14.8	10.9
02	9.9	21.4	19.5	20.0
03	8.3	12.4	10.0	6.2
04	8.9	11.9	11.6	11.7
05	12.6	-3.5	-1.3	2.3
06	31.3	32.7	31.8	27.8
07	3.7	2.7	6.5	3.9
08	12.6	13.6	13.8	12.5
09	4.4	4.6	9.7	10.2
10	14.2	16.2	10.2	10.9
11	11.8	11.1	5.6	6.3
12	13.7	12.7	13.0	9.5
13	11.3	14.2	12.0	13.6
14	8.4	8.4	5.7	5.5
15	7.1	8.4	9.7	8.0

EMG Activity of Back Muscles at the L_3 Level, expressed as a percentage of a standard stress, for 15 subjects with four positions of seat height.

	Position			
Subject	1	2	3	4
01	11.8	2.8	8.2	4.9
02	6.8	9.2	6.4	10.6
03	4.8	6.9	4.8	5.2
04	5.6	6.3	4.8	5.8
05	2.8	-0.7	-0.3	0.8
06	11.1	11.5	8.6	11.2
07	3.8	3.2	4.1	2.6
08	10.0	9.4	11.8	8.7
09	10.7	5.2	7.0	8.5
10	4.8	9.5	8.2	9.4
11	5.2	5.0	4.1	5.0
12	6.7	6.9	6.6	4.5
13	3.4	5.3	4.3	4.8
14	5.4	5.4	5.6	6.9
15	4.7	5.3	6.1	4.5

EMG Activity of Back Muscles at the L_5 Level, expressed as a percentage of a standard stress, for 15 subjects with four positions of seat height.

	Position			
Subject	1	2	3	4
01	4.3	2.0	2.4	2.9
02	5.3	2.8	1.8	4.9
03	2.4	4.4	2.6	2.6
04	-1.3	0.9	0.0	0.2
05	1.3	1.3	0.4	1.2
06	7.5	8.2	6.2	7.2
07	6.2	2.9	5.5	3.7
08	7.5	6.2	7.5	5.2
09	3.1	3.0	5.3	8.6
10	7.7	3.8	3.8	15.4
11	4.1	6.0	6.9	9.4
12	5.9	7.5	6.2	5.1
13	4.8	2.6	4.5	5.6
14	7.0	5.9	5.3	6.0
15	2.1	6.9	7.1	5.9

Assessment of Comfort Raw Data. Positions were ranked on a scale of one to four, with one being the most comfortable and four being the least comfortable.

	Assessment of Comfort			
Subject	Position One	Position Two	Position Three	Position Four
01	1	2	4	2
02	2	4	1	3
03	2	1	3	4
04	3	1	2	4
05	3	4	2	1
06	2	4	3	1
07	1	3	2	4
08	2	4	1	2
09	3	4	1	2
10	1	3	2	4
11	1	2	4	3
12	1	4	3	2
13	2	3	1	4
14	1	4	3	2
15	2	1	3	4